

AIRBORNE HYPERSPECTRAL SCANNER (AHS) SPECTRAL EMISSIVITY RETRIEVAL IN 8-13 μm .

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ABSTRACT

Multispectral and hyperspectral thermal sensors can use spectral emissivities for mapping surface elements that show wavelength emission differences (typically minerals). The Airborne Hyperspectral Scanner (AHS) is a VIS to TIR 80 band line-scanner which collects 10 bands in the 8 to 12 μm atmospheric window, with 0.4 μm bandwidth. Multichannel temperature-emissivity separation published methods (*Reference Channel* and *Emissivity Normalization*) are evaluated here to estimate the capacity of AHS to retrieve spectral emissivity.

These methods are very dependent on an accurate calibration and atmospheric correction of the at-sensor radiances, and also sensitive to the noise equivalent difference temperature (NEAT) of the channels. Emissivities obtained for some AHS 2005/2006 imagery campaigns, including day and night flights, have been tested comparing with emissivity ground truth (collected at SEN2FLEX ESA 19187/05/1-EC project) and spectral libraries available in the 8-13 μm region.

1. INTRODUCTION

In the thermal infrared (TIR) domain, the emissivity is an important parameter for mapping surface temperature and composition (Sobrino et al, 2006). In addition, inside the 8-12 μm atmospheric window mineral groups such as silicates, carbonates, sulphates exhibit measurable absorptions bands that permits mineral species identification (Vaughan et al, 2003). With this background, space missions like: Moderate Resolution Imaging Spectrometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), include multispectral TIR images

Emissivity of surfaces is wavelength dependent, and is function of composition, roughness, and physical parameter e.g. moisture content (Schmugge, 2002). Multispectral airborne thermal infrared sensors such as: Thermal Infrared Multispectral scanner (TIMS), Airborne Hyperspectral scanner (AHS), and thermal hyperspectral like: Airborne Reflective/Emissive Spectrometer (ARES) and Spatially Enhanced Broadband Array Spectrograph System (SEBASS), offer the possibility to obtain spectral emissivity maps at regional scale and improve the emissivity knowledge to develop space missions.

Considering a multichannel thermal sensor, several methods have been proposed in recent years to separate temperature and emissivity (Li et al, 1999). Table 1 shows references for some of these algorithms.

Method	Reference
Temperature-Independent Spectral Indices (TISI)	Becker and Li (1990; 1995)
Reference Channel Method (REF)	Kahle et al (1980)
Normalize Emissivity Method (NEM)	Gillespie (1985)
Alpha Emissivity Method (α)	Kealy and Gabell (1990)
Temperature and Emissivity Separation (TES)	Gillespie (1998)

Table 1: Temperature and Emissivity separation methods references.

The Spanish National Institute for Aerospace Technology (INTA) owns and operates the Airborne Hyperspectral Scanner (AHS). AHS is an imaging spectrometer with complete spectral coverage (VIS to TIR), having multispectral in the MIR and TIR regions. INTA has the goal to offer spectral emissivity product as a deliverable for users, with this aim this work evaluate the accuracy and performances of the AHS emissivity retrieval applying, in a first approach, REF and NEM methods implemented in ATCOR4 (Dr. R. Richter, DLR and ReSe Applications Schläpfer) and ENVI (ITT Industries, Inc) software.

2. AIRBORNE HYPERSPECTRAL SCANNER (AHS)

The AHS is an airborne line-scanner imaging spectrometer manufactured by ArgonST (formerly Sensytech Inc.). Collects 80 bands from 0.45 to 12.8 microns inside atmospheric windows. It is installed in the INTA's aircraft (CASA C-212) and is integrated with INS/GPS Applanix POS-AV 414. The main characteristics of AHS are:

FOV / IFOV : 90° / 2.5 mrad			
Scan rates: 12.5, 18.75, 25, 35 r.p.s., (pixel 7 to 2 meters).			
Digitization precision: 12 bits to sample the analog signal, with gain level from x0.25 to x10.			
Two controllable thermal black bodies within the field of view.			
PORT	spectral coverage(μm)	n° of bands / FWHM (nm)	$\lambda/\Delta\lambda$ (minimum)
Port 1	0.43 > 1.03	20 / 28 nm	16
Port 2A	1.55 > 1.75	1 / 200 nm	8
Port 2	2.0 > 2.54	42 / 13 nm	150
Port 3	3.3 > 5.4	7 / 300 nm	11
Port 4	8.2 > 12.7	10 / 400 nm	20

Table 2: AHS characteristics

3. MATERIAL

3.1 AHS data set

Two different AHS imagery were used to assess the emissivity retrieval. The imagery selected have, within the scene, surfaces with different emissivities: one group is with high and featureless emissivity spectrum like water and vegetation, and another group is with absorption presence like minerals. The images were acquired in the framework of two different projects:

Exploitation of AnGular effects in Land surface form satellites (EAGLE2006, ESA). AHS image was acquired over Ermelo (The Netherlands) on 13th June 2006, with a pixel of 6.8 meters.

At instances of Spanish National Institute for Agrarian research (INIA), INTA acquired on 10th October 2006 an AHS flight campaign over 1200 ha burned area in Guadalajara (central Spain).

3.2 Software applied

Two commercial software were used to retrieve emissivity for AHS imagery. Both applications include NEM and REF emissivity methods and were applied to AHS data set selected.

ATCOR4: Dr. R. Richter, DLR and ReSe Applications Schlöpfer (<http://www.rese.ch/atcor/atcor4/index.html>). Specific atmospheric correction application for airborne images.

ENVI: ITT Industries Inc, 2006 (<http://www.RSInc.com/envi>) Remote Sensing software.

3.3 Validation data

To serve as validation for the AHS emissivity performance, field data and spectral libraries were gathered.

3.3.1 Field data

In the framework of EAGLE2006 ESA project, Global Change Unit of the University of Valencia (Spain), collects over a quartz sandy area, thermal radiometric measurements with the multiband radiance-based thermal radiometer CIMEL CE312. The measurements were carried out at the same day of an AHS flight line.

Field radiometric measurements were processed to temperature and emissivity using TES (see Table 1) (Jiménez-Muñoz, et al, 2006)

3.3.2 Spectral library

Emissivity spectra were taken from two distinct spectral libraries: John Hopkins University (Salisbury and D'Aria, 1992) available in the ENVI spectral library format. The original directional hemispherical reflectance data was converted into directional emissivity data using Kirchoff's law $\epsilon=1$ (Vaughan, 2003). The other spectral library was MODIS USCBS, in this case the spectrums are directly on emissivity and ascii format.

For the comparison between image emissivity and spectral library, the spectrums selected were for two groups indicated: featureless and with absorptions. Spectrums selected, as it can be seen in figure 1, were also generic (e.g for coniferous forest in the image we select pine spectrum from spectral library), In this work we only want to evaluate the AHS emissivity output

in a first approach. The original spectrums were resampled with AHS responsivity functions, which could be seen on figure 2.

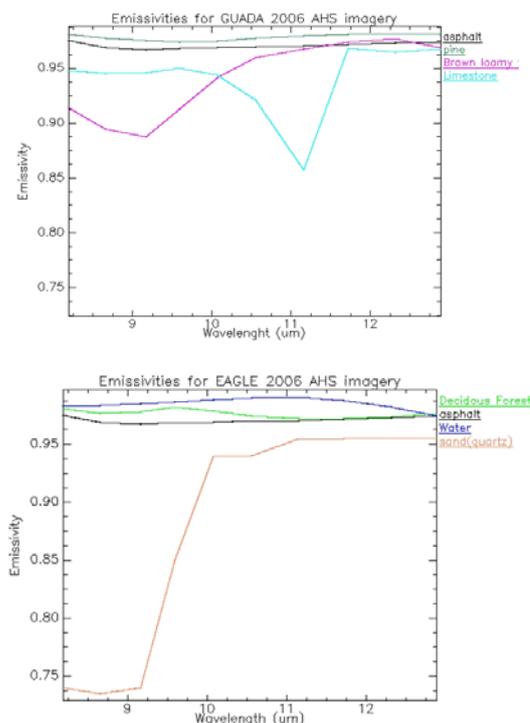


Figure 1: Resampled emissivity spectrums selected from spectral libraries for AHS imagery validation.

4. METHODS

4.1 Calibration: at-sensor radiance

AHS has two onboard calibration blackbody (BB) for thermal reference. Those BB are controllable in temperature range of -15°C (cold BB) at +25°C (hot BB) with respect to scan head heat sink temperature. The sensor measures in each scan line, in the beginning the cold BB, and at ending, the hot BB. AHS data were calibrated to at-sensor radiance using linear interpolation between cold and hot BB measured radiances and Digital Value registered. BB radiance were calculated with temperature Planck inverted, using for each channel corresponding responsivity functions of Figure 2. For EAGLE 2006 AHS flight line coldBB =21°C and hotBB=50°C, in the case of GUADA 2006 AHS flight line coldBB =16°C and hotBB=45°C.

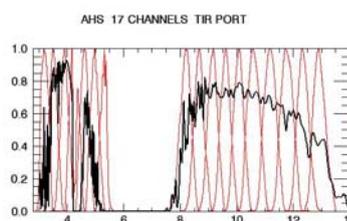


Figure 2: AHS MIR/TIR spectral responsivity functions plotted against atmospheric transmittance.

4.2 Atmospheric correction: at-surface radiance

In order to extract the surface temperature and emissivity from the image, it is necessary to perform an accurate atmospheric correction (Richter et al, 2005). ATCOR4 and ENVI thermal modules have different ways to correct for atmospheric effect on the observed spectral radiances:

4.2.1 Atmospheric correction using ENVI (ISAC)

In ENVI case, to compensate atmospheric effect, uses the In-scene Atmospheric Compensation (ISAC), developed by Aerospace corporation (SEBASS team: Johnson, 1998). ISAC is based assumption that for a given wavelength, there are measurements within the scene of a material with an emissivity nearly one (e.g vegetation or water). ISAC compensates for atmospheric transmission and upwelling radiance, assuming an atmospheric conditions homogeneous across the image but not for the effects of reflected downwelling radiance (Vaughan et al, 2003). ISAC method can be divided in following sequence steps:

- A channel with high atmospheric transmittance ($\tau \sim 1$) is chose
- Compute apparent brightness temperature T_b with a constant emissivity (e.g. $\varepsilon = 0.97$)
- For the remaining channels a comparison in a scatter plot, between measured radiance and computed radiance, using calculated T_b , is applied.
- A straight line to the upper boundary of the points is fit. In this linear model the slope is proportional to transmittance (τ) and the offset is proportional to the path radiance (L_{pth}).

Using ISAC on ENVI let you to choose two parameters for a best linear model performance: regression pixels and fitting technique. The first parameter indicate all or "MaxHit" only for pixels that have maximum brightness temperature at the channel selected as reference. For the second parameter the options are to fit over "Top of the Bins", means the pixels whose emissivity is close to 1, or reducing the pixels inside an area of 3 times a Nose equivalent sensor response (NESR) value. After an iterative analysis testing the parameters, the atmospheric correction ISAC outcome was processed with All-pixels and a fitting over an area of 0.35 NESR.

4.2.2 Atmospheric correction using ATCOR4

Following Richter et al 2005, the radiance equation in the thermal domain can be written as:

$$L_{sen} = L_{pth}^{\uparrow} + \tau_k (\varepsilon_k B_i(T_s)) + \tau_k (1 - \varepsilon_k) \frac{F_k^{\downarrow}}{\pi} \quad (1)$$

Where:

L_{sen} at-sensor radiance

L_{pth} thermal path radiance

τ transmittance

ε emissivity

T_s surface temperature

B blackbody radiance at T temperature

F thermal downwelling flux on the ground

ATCOR4 is based on the radiative transfer code MODTRAN4 (Berk et al 2000), is an specific application for atmospheric correction of airborne hyperspectral imagery. ATCOR4 estimates solar illuminations and atmospheric conditions using atmospheric look-up tables from MODTRAN4, having the

possibility to estimate atmospheric water vapor and visibility directly from the image, taking into account radiometric response in specific AHS channels. Water vapor is the main atmospheric constituent that affects the signal in the thermal domain. ATCOR4 estimates the water vapor using AHS reflective channels in the 940 nm region and the atmospheric pre-corrected differential absorptions (APDA by Schläpfer et al 1998).

4.3 Emissivity retrieval

For sensors with n thermal channels there are n equations with $n+1$ uncertainties, it is an undetermined system with n emissivities plus a surface temperature (Richter et al, 2005). To address this problem the developed temperature and emissivities methods has to make some assumptions like consider a constant emissivity in one channel, but this is method depend. In this work we assess the performance of REF and NEM methods implemented in both software.

4.3.1 REF method

REF method was developed by Kahle et al (1980). The method assumes that emissivity in one channel has constant value for the entire image. For the channel selected the surface temperature is obtained for each pixel, the temperature calculated serves for the remaining channels emissivity calculation.

In order to test the AHS channel to be the channel reference, the imagery were process with all channels. The best channel was channel AHS 75, that also has the highest transmittance as it can be seen on Figure 2.

4.3.2 NEM method

NEM was developed by Gillespie (1985). The method assumes a constant emissivity in all the channels for a given pixel. All channels temperature was estimated and the maximum is considering the surface temperature. Using equation (1) all channel emissivity were derived.

In order to test the emissivity selection, the imagery was processed with interval emissivity from 0.96 to 0.99. The constant emissivity selected was 0.98 to be closer to water and vegetation and test the output for absorptions surfaces (quartz sand)

5. RESULTS

5.1 Atmospheric correction validation

The atmospheric correction is the first step to emissivity retrieval. The software proceed with different correction methods so a comparison between them for the same AHS data set is performed. Figure 3 shows this comparison for AHS EAGLE 2006 using a priori "cold" surface (e.g. water) and "hot" surface (e.g. sand). Taking into account also this comparison for AHS GUADA imagery, ISAC method outcomes a 5% less surface radiance than ATCOR4. Also it is important for emissivity retrieval to perform an accurate atmospheric correction. In order to evaluate atmospheric correction, surface temperature is compared between software output and field measurement. The field temperature measured in the EAGLE 2006 quartz sand point with CIMEL CE312, serves as validation, the average temperature at the flight time was 324° K, AHS only deviates 1° in ATCOR-4 the output and 1.5°K in ISAC outcome.

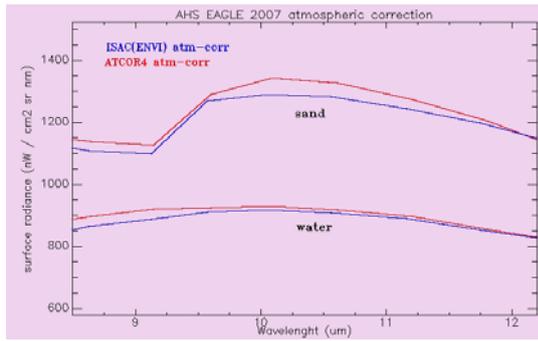


Figure 3: Surface radiance comparison between ATCOR4 and ISAC (ENVI) atmospheric correction output.

5.2 Emissivity retrieval validation

Both emissivity methods and software were used to gather emissivity from AHS data set. For each AHS flight line four emissivity imagery were obtained. Although emissivity images are very noisy, as it can be seen on Figure 4 for the example of EAGLE, surfaces are discernable using decorrelation stretch with AHS emissivity channels AHS 73,76,78. (water=blue, Deciduous forest=magenta, asphalt= cyan, and sand= green)

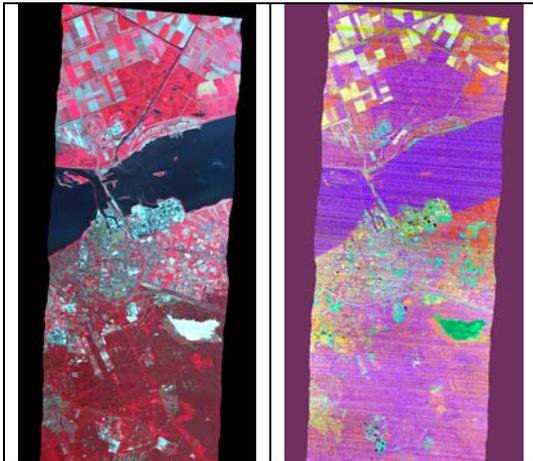


Figure 4: EAGLE 2006 imagery subset over Ermelo (The Netherlands). Left: RGB false color VNIR channels. Right: Decorrelation stretch of emissivity channels AHS 73,76,78.

For each AHS data set, four surfaces serves as evaluate the emissivity results. For each surface, comparisons between validation spectrum (see figure 1) and spectrum extract from imagery was applied. The comparison was realized for all the channels obtaining the deviation among methods along wavelength. Figure 5 shows the deviation calculated for all surfaces and methods, graphics indicates: dotted ATCOR4-NEM, dashed ATCOR4-REF, dash dot ENVI-NEM and solid ENVI-REF

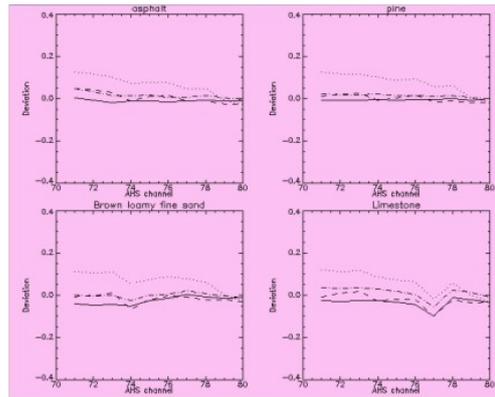
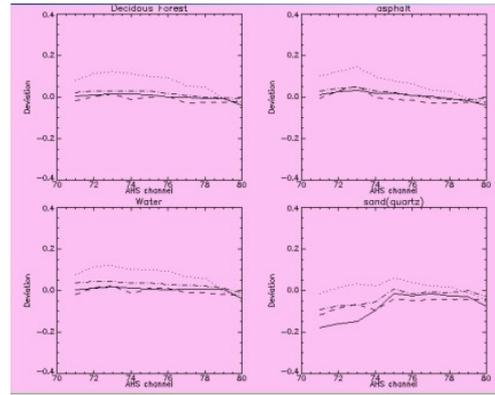


Figure 5: Emissivity deviation calculated for all surfaces and methods. Upper: EAGLE2006 and Bottom: GUADA 2006. Lines indicate: dotted ATCOR4-NEM, dashed ATCOR4-REF, dash dot ENVI-NEM and solid ENVI-REF

6. CONCLUSIONS

Both atmospheric correction methods perform very similar for gathering surface radiance, taking into account hot and cold areas, and obtained an accurate surface temperature comparing with only one field validation point.

AHS emissivity retrieval using REF and NEM had obtained encouraging results. The deviation gathered between AHS emissivity and validation data, were not higher than 0.05 except for ATCOR4 NEM method, that seems to have a bias. On the contrary this method performs better for absorptions surface like quartz sand.

A deeper evaluation for methods applied is required, in terms of image noise and parameters selection such us: reference channels and constant emissivity.

7. REFERENCES

- Fernandez –Renau, A. Gómez, J.A. and De Miguel, E. (2005). The INTA AHS system. Proceedings. SPIE Int. Soc.Opt. Eng. 5978, 59781L.
- Jiménez-Muñoz, J.C. and Sobrino, J.A. "Emissivity spectra obtained from field and laboratory measurements using the temperature and emissivity separation algorithm," *Appl. Opt.*, vol. 45, no. 27, 7104-7109, 2006.
- Li, Z. 1999. Evaluation of six methods for extracting relative emissivity spectra from thermal infrared images. *Remote. Sens. Env.* 69:197-214.
- Richter, R. et al 2005. Spectral and radiometric requirements for the airborne thermal imaging spectrometer ARES. *International Journal of Remote Sensing*. 26.15 3149-3162
- Schmugge et al. 2002. Temperature and emissivity separation from multispectral thermal infrared observations. *Remote. Sens. Env.* 79,189-198
- Sobrino, J.A. et al. 2006. Land surface temperature derived from airborne hyperspectral scanner thermal infrared data. *Remote. Sens. Env.* 102,99-115
- Vaughan, R.G. 2003. SEBASS hyperspectral thermal infrared data: surface emissivity measurement and mineral mapping. *Remote. Sens. Env.* 85,48-63

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